Development and Demonstration of Advanced Tooling Alloys For Molds and Dies

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Overview

Idaho National Engineering & Environmental Laboratory - University of California, Davis

Project Partners:

RSP Tooling, LLC
Solon, OH

Glass Manufacturing Industry Council
Westerville, OH

General Aluminum Manufacturing Co.
Conneaut, OH

- Project overview
- Benefits
- Technical plan and accomplishments
- Commercialization activities

Project Summary

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- **Project title:** Development and Demonstration of Advanced Tooling Alloys For Molds and Dies
- **Collaboration** between INEEL, UC-Davis, and an industry team (RSP Tooling LLC, Glass Manufacturing Industry Council, and General Aluminum Manufacturing Co.).
- **Status**: Second year of a four-year project
- **Objectives**
  - Increase die life for glass manufacture, stamping, forging and die casting by 20% by providing improved die materials.
  - Reduce energy consumption associated with the manufacture and heat treatment of dies by a minimum of 25% by eliminating unit operations in processing, and reducing energy usage during heat treatment.
  - Benchmark properties of spray-formed tool steels, modify alloy chemistry to take advantage of rapid solidification, and produce dies for in-service evaluation.

Main R&D Activities

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- Industry partners choose tooling alloys to be studied and provides die designs for stamping, forging, die casting and glass component manufacture.
- Benchmark microstructure and material properties of dies processed by spray forming.
- Model heat transfer, solidification, and momentum phenomena associated with spray forming of dies.
- Tailor alloy chemistry and heat treatment to rapid solidification.
- Perform in-service lifetime and failure mode analysis by industry.
- Reduce energy consumption and scrap.

Project Team

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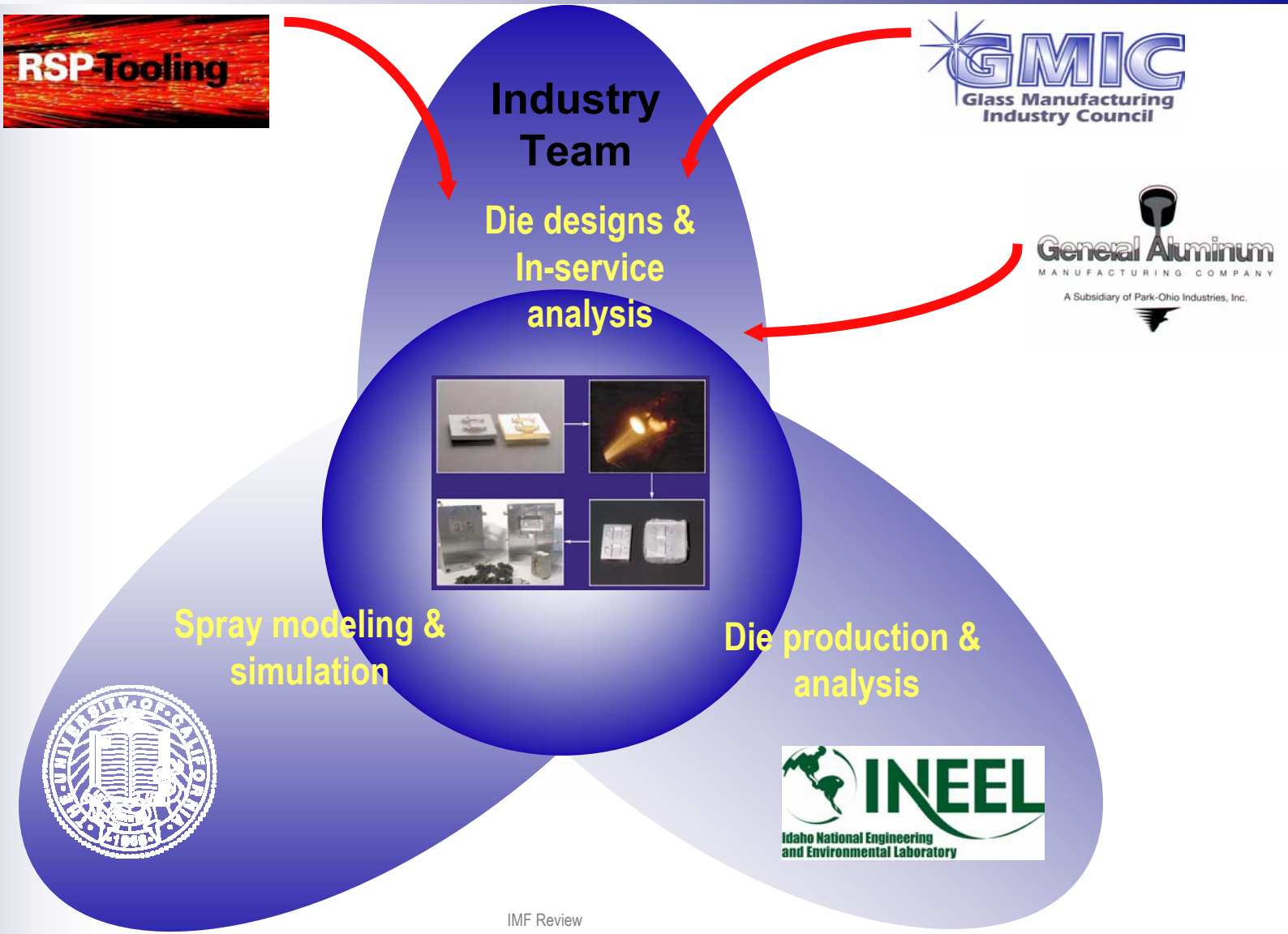

R&D is guided by industry need for improved die materials and processing methods

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IOF or Supporting Industry	R&D Need	Roadmap or Industry Vision Reference
Steel	Materials and manufacturing methods for die materials and sheet forming die development. Development of additional methods for materials and manufacturing, especially for short-run tooling.	*Steel Technology Roadmap,* pp.133-134, 137, 139, 145.
Glass	Improved hot glass contact materials, e.g., molds and rolls	*Report of the Glass Technology Roadmap Workshop,* Exhibit 1-2: Long-Term (10+ year) High priority Research Needs. p. 7.
Metal casting	Development of die materials to eliminate solder and heat checks in permanent cast applications.	*Metalcasting Industry Technology Roadmap,* Exhibit 4-3. Manufacturing Technology. Mid-Term (3-10 years), High Priority Research Need. p.37.
Forging	Advanced die materials	*Forging Industry Vision* Appendix A: Forging Industry Needs - Production Efficiency. P.14.
Heat treatment	Savings in use of primary energy per unit production of 25-60%	*Roadmap for Process Heating Technology,* Exhibit 7.3, p.39

Funding and Industry Cost Share

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Year	DOE Funding ($K)	Industry Cost Share
Year 1	$180	TBD
Year 2	$200	TBD
Year 3	$240	TBD
Year 4	$170	TBD
Total	$790	$275

RSP Tooling Approach

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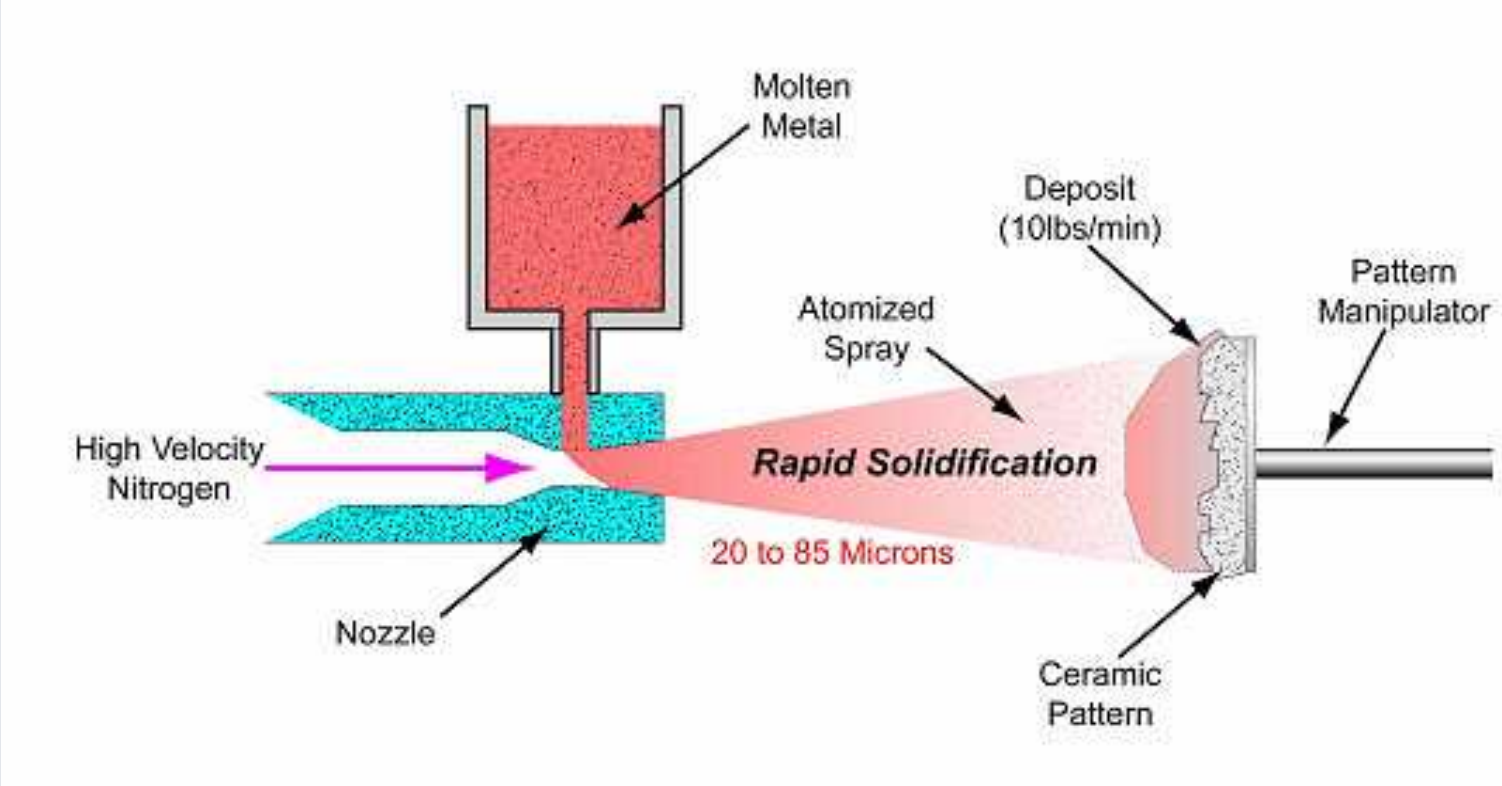

RSP Tooling – Technology Overview

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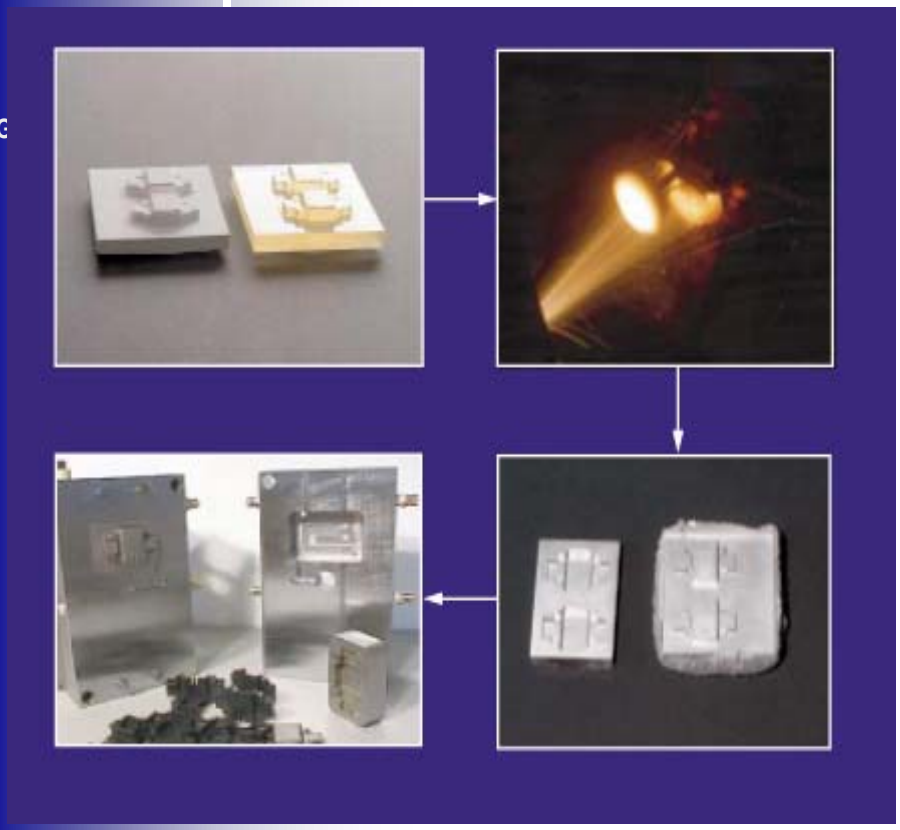
Project Partners:



Processing steps

- Molds and dies are used to manufacture nearly all mass produced products. Traditionally, they are machined from a block of steel.
- With RSP Tooling, a spray of molten steel droplets accurately captures the shape and details of a pattern.
- By eliminating machining, grinding, polishing and heat treatment unit operations, RSP Tooling reduces cost and turnaround time for molds and dies.
- R&D 100 Award winner, Energy@23 Award winner, and Federal Laboratory Consortium Award winner.

Benefits

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- Low-cost tooling.
- Short design-to-part cycle.
- Allows prototypes to be produced from material of choice and process of choice.
- Can go directly from prototype into production.
- Elimination of unit operations, e.g. machining, grinding, polishing.
- Die life extension.
- Can be used for most tooling alloys.
- Potential for conformal cooling of molds.

Benefits (cont.)

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- Excellent replication of pattern details.
- High dimensional accuracy.
- Lower cost starting material.
- Reduced capital equipment costs.
- Mold and die properties (e.g. hardness, toughness, thermal fatigue resistance, strength, etc.) can be tailored by either of two heat treatments:
  - Artificial aging without risk of tool distortion.
  - Conventional heat treatment.
- Significant Energy savings.

Sources of Energy Savings

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- Elimination of steel mill unit operations for producing forged plate, rod, bar, etc. suitable for the demands of die-casting, stamping, forging, etc.
- Elimination of many of the machining, grinding, and polishing unit operations necessary to transform the forged steel into molds and dies.
- Potential for die life extension as a result of unique microstructural qualities found in rapidly solidified tool steel.
- The ability to heat-treat the tool steel using relatively low temperature artificial aging rather than conventional autenitization/quench/temper heat treatment.

Energy Savings

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Processing Step	*Current Energy Use (trillion BTU/yr)*	*With New Technology (trillion BTU/yr)*	*Energy Savings* (trillion BTU/yr)*
Elimination of steel mill unit operations	10.00	0.33	9.67
Elimination of machining operations	3.75	1.00	2.75
Potential for die life extension	0.92	-	0.92
Die heat treatment	6.70	0.94	5.76
Summary	21.37	2.27	19.10

Electricity is 91.5% of total.
Natural gas is 4.4% of total
Oxygen is 4.1% of total

Work Plan & Responsibility Chart (Years 1 & 2)

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All tasks are on schedule

Tooling Alloys Selected by IOF Partners and Tooling Requirements

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IOF	Alloy	Application	Tooling Requirements
Glass	Gray iron, A2	Glass molds	High thermal conductivity, thermal shock resistance
Forging	M2, H13	Hot forming dies	High temperature strength, wear resistance, and toughness,
Metal Casting	H13	Die casting dies	Thermal fatigue resistance, high temperature strength, wear resistance, and toughness,
Steel	A2, H13	Cold forming (stamping) dies for sheet metal.	Wear resistance, toughness and compressive strength

Accomplishments

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Process Development

- Developed freeze casting procedures for high accuracy tool patterns.
- Adapted press to spray forming chamber.

Die Manufacture and Industry Analysis

- Provided dies to industry partners for in-service analysis in die casting and forging.
- Provided dies to industry partners for dimensional analysis.

Modeling and Simulation

- Numerical analysis (finite element method) of stresses that develop during spray forming.

Microstructure & Property Analysis of Spray-Formed Dies

- XRD analysis of residual stress of as-spray formed A2 steel.
- Residual stress analysis of H13 die sample by neutron diffraction (with Chalk River Laboratories, NRC Canada).

Accomplishments (cont.)

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- Evaluated temper response of spray-formed/conventionally heat treated H13 tool steel.
- Performed Differential Thermal Analysis (DTA) of H13.
- Evaluated softening behavior of spray-formed H13 tool steel.
- Performed preliminary microstructural analysis of spray-formed M2 and A2 tool steels.

Completed Industry Production Runs

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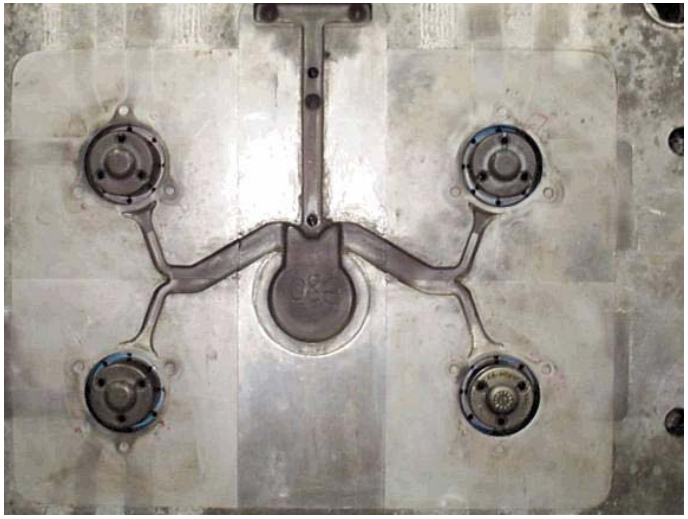
- Piston cover dies for aluminum die casting (alloy 390).
- Spray-formed H13 dies run side-by-side with conventional machined dies are shown mounted in holding block.
- Spray-formed dies were run in overaged condition.
- Spray-formed dies outlasted conventional dies by 25%



- Spray-formed & conventionally heat treated M2 tool steel forging die (right) used to produce steel gears (left).
- SF die produced suitable number of parts to be classified as a production run. Die life extension not observed. Same failure mode as with machined dies.

Current Industry Production Runs

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- Seal plug die for aluminum die casting.
- SLA master (lower right), RTV (lower left), ceramic (upper left) and spray-formed die insert (upper right).
- Die is running in as-deposited condition in die casting shop in OH.

- Aluminum die casting.
- SLA masters (above), RTVs (far left and right), ceramic pattern (center) and as-deposited H13 tool steel die casting dies (below).
- Dies are running in overaged condition in shop in Italy.

Future Industry Production Runs

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- H13 tool steel forging die for stainless steel plumbing fittings.
- SLA master (above left), ceramic (above right), and as-deposited H13 forging die (below).

- A2 tool steel mold for glass components.
- SLA master (above), ceramic (far right), and as-deposited A2 mold section (far left).

Dimensional analysis of spray-formed tools and ceramic patterns

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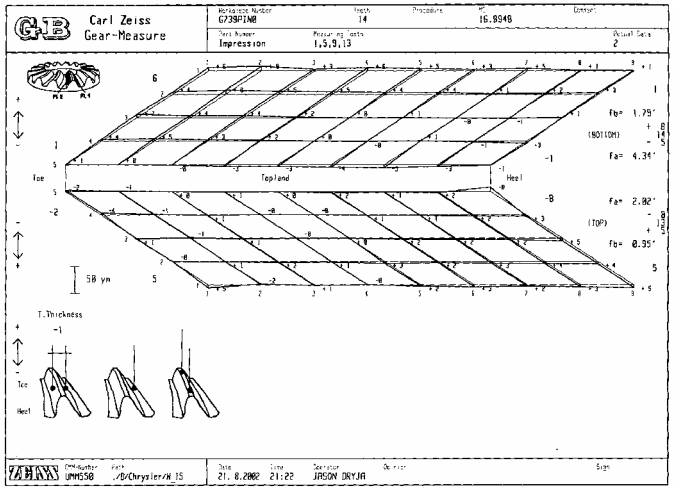
- Very tight tolerance required for tooth form (+/- 0.03 mm) of gear forging die
- Slip cast and freeze-cast Al_2O_3ceramic formulations tested for accuracy.
- Freeze-cast ceramic formulation provided accuracy results that were excellent and consistent.
- Accuracy of spray-formed dies will be evaluated.



Residual stress modeling. Axial and radial stress distributions (finite element method)

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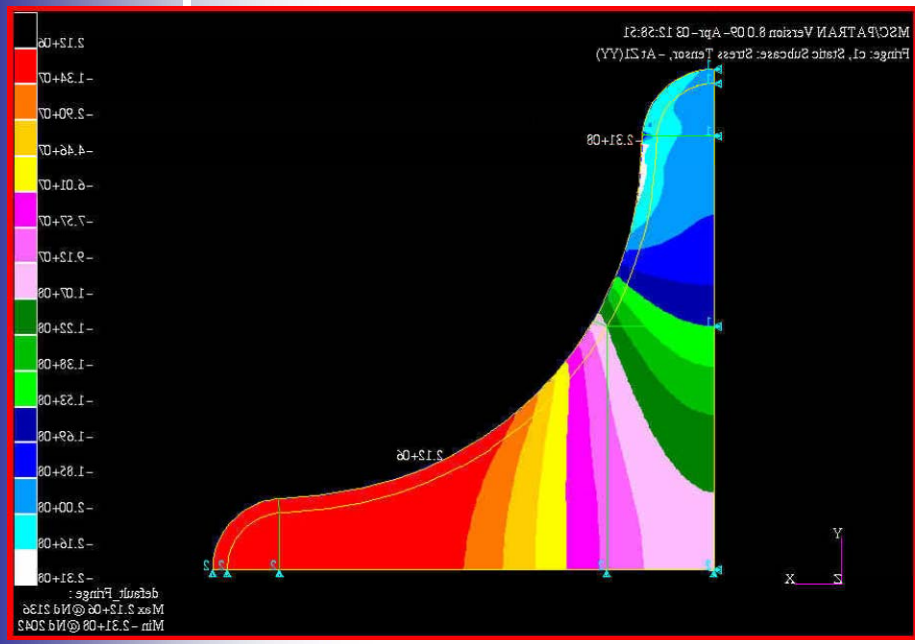
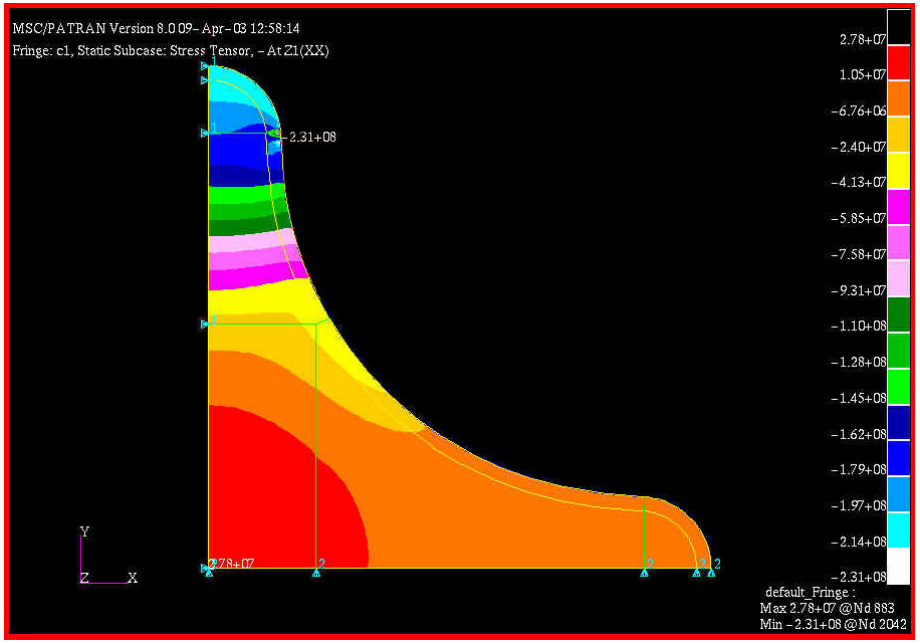
Axial Stress

- Compressed in most area
- Tensile only in peripheral zone
- Magnitude of axial stress decreases from surface band to bottom band and peripheral zone

Radial Stress

- Compressed in the upper zone
- Tensile in the bottom and peripheral zones
- Radial stress in the upper region has higher magnitude than that in the lower region.





Photomicrographs of H13 tool steel

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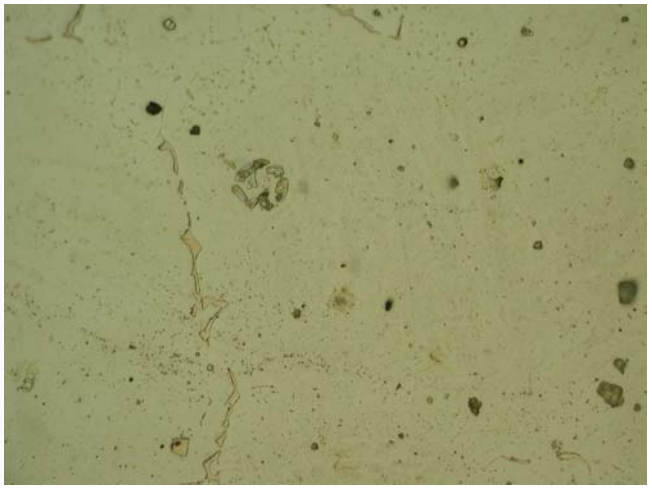
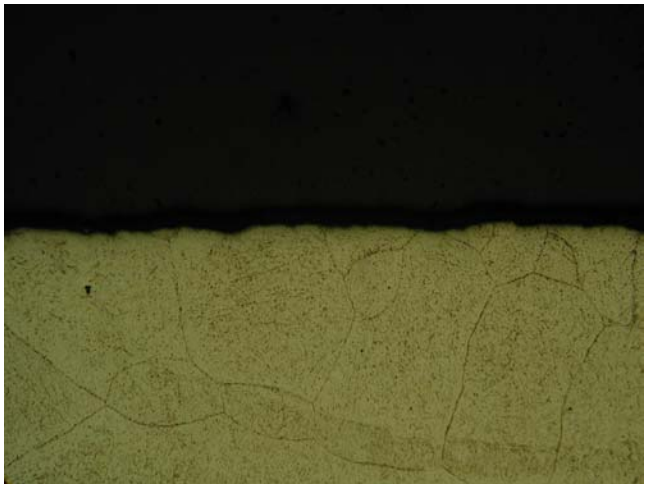
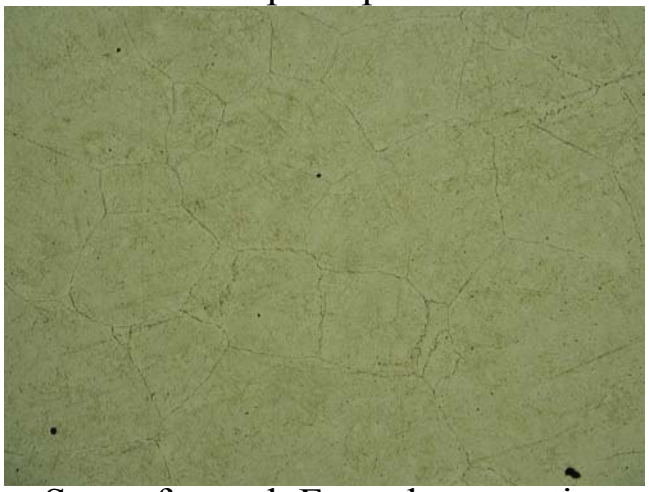


Cast, polished



Spray formed. Free convection cooled. Deposit/pattern interface

Spray formed. Free convection cooled. Interior



Spray formed. Forced convection cooled. Interior

Element maps of spray formed/aged (540°C, 2hrs. + 580°C, 2hrs.) H13 tool steel

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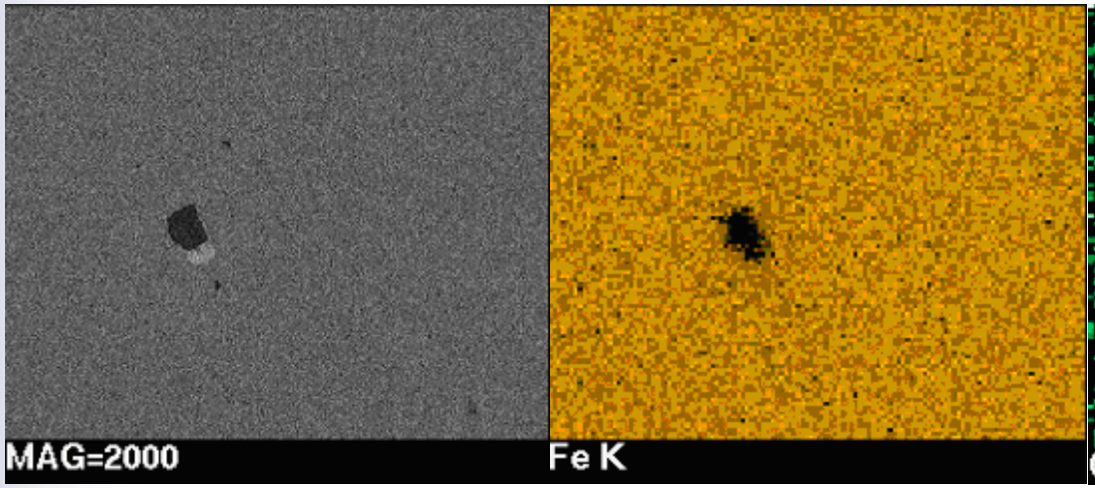

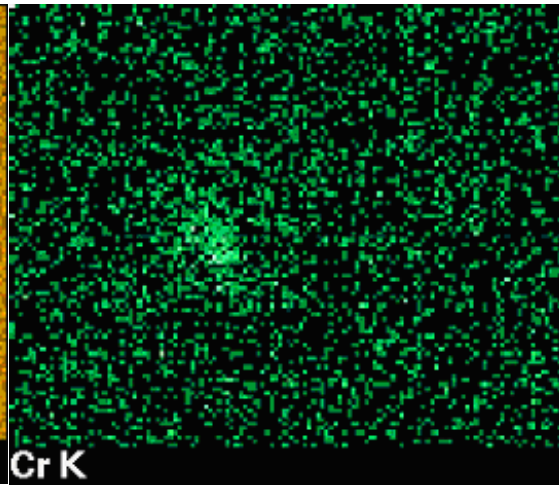

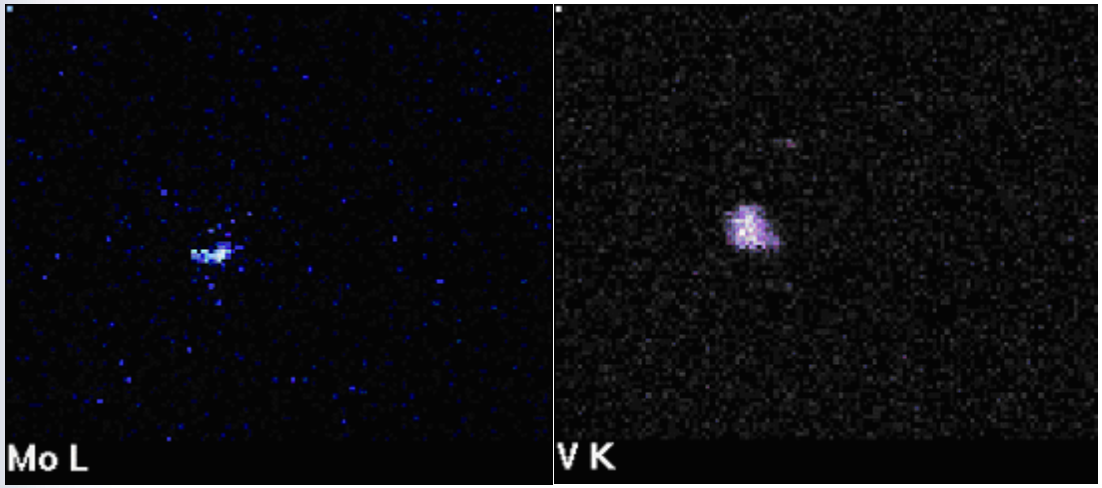

SEM photomicrographs (BSE mode) of spray formed/aged (540°C, 2hrs. + 580°C, 2hrs.) H13 tool steel

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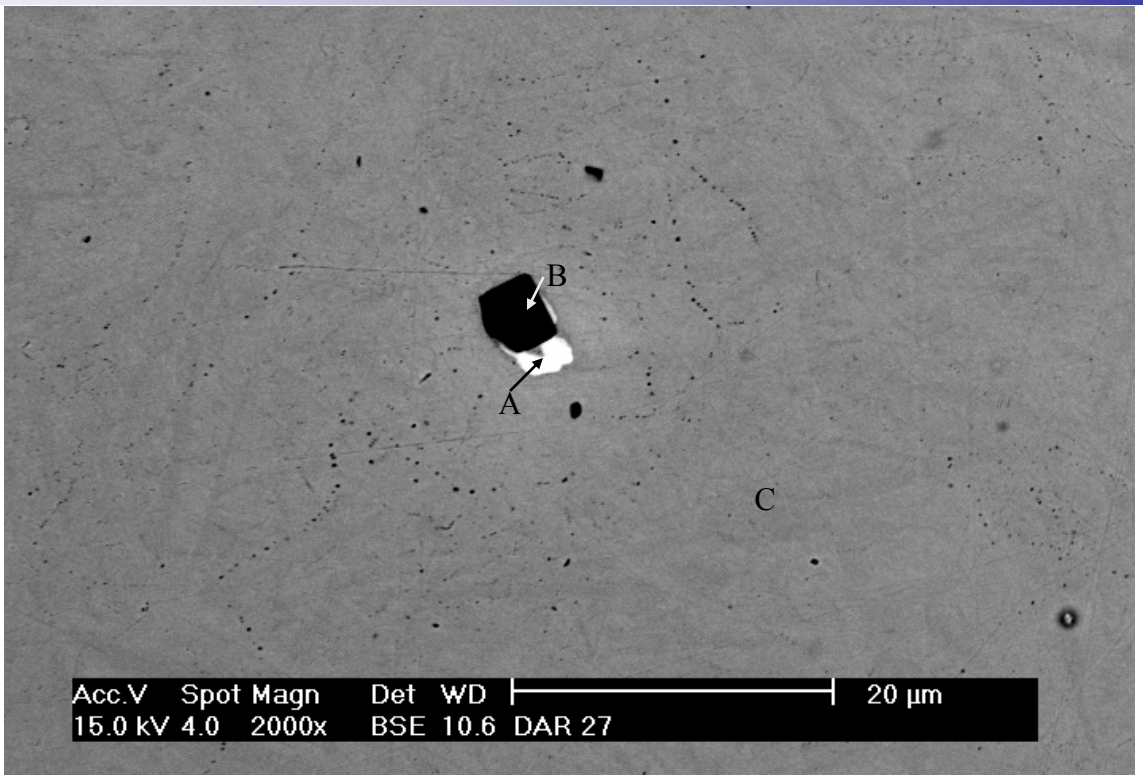

Spot	Fe (Wt%)	Cr (Wt%)	V (Wt%)	Mo (Wt%)	Mn (Wt%)	Si (Wt%)
A	81.65	7.55	1.11	6.86	1.47	1.36
B	3.25	8.19	84.40	4.07	0	0.09
C	89.38	5.16	1.01	1.73	1.45	1.27

Temper response of heat treated H13 tool steel. Samples were tempered 2 hr. at indicated temperatures.

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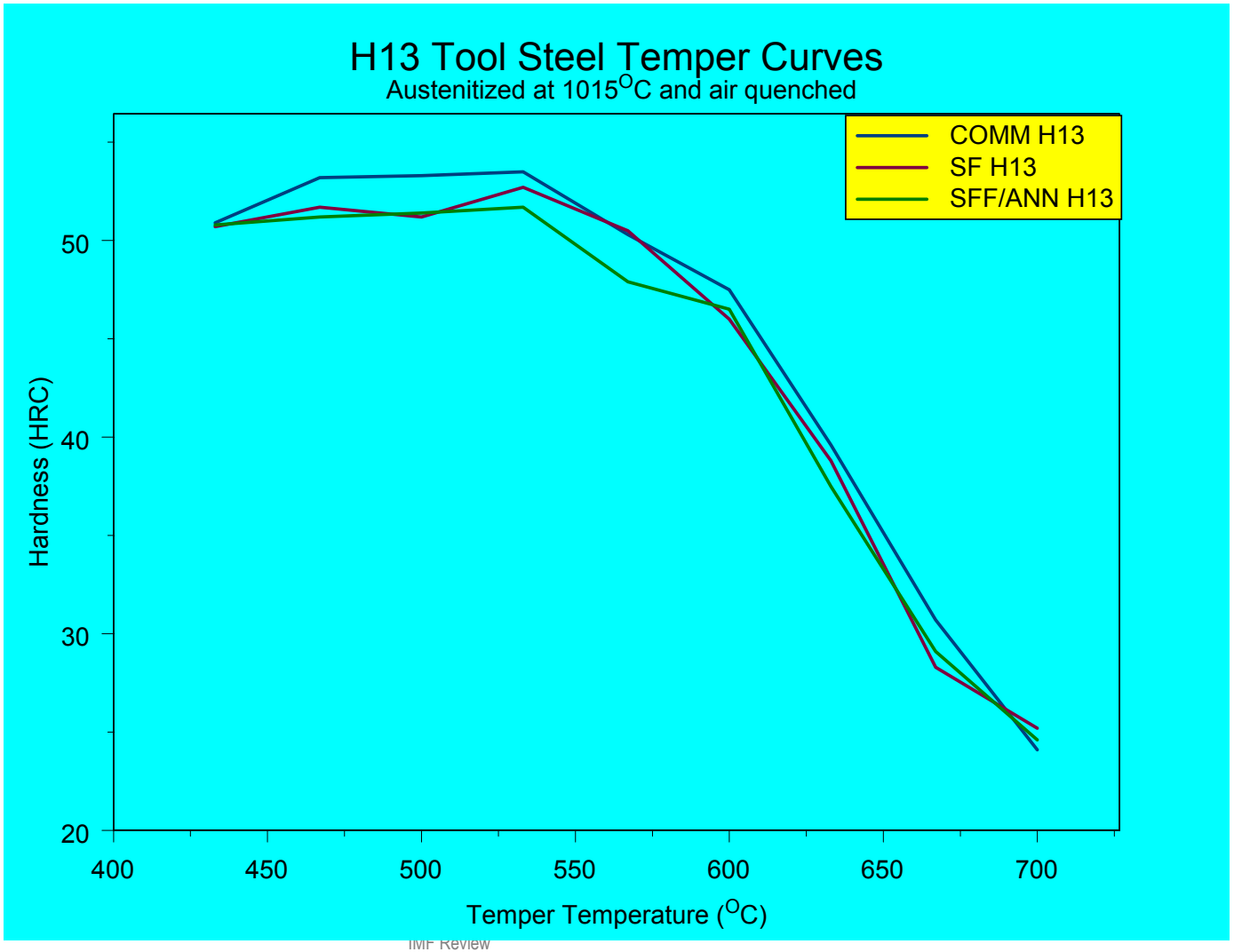

Differential Thermal Analysis (DTA) scans of austenitized (1015°C)/air quenched H13 tool steel

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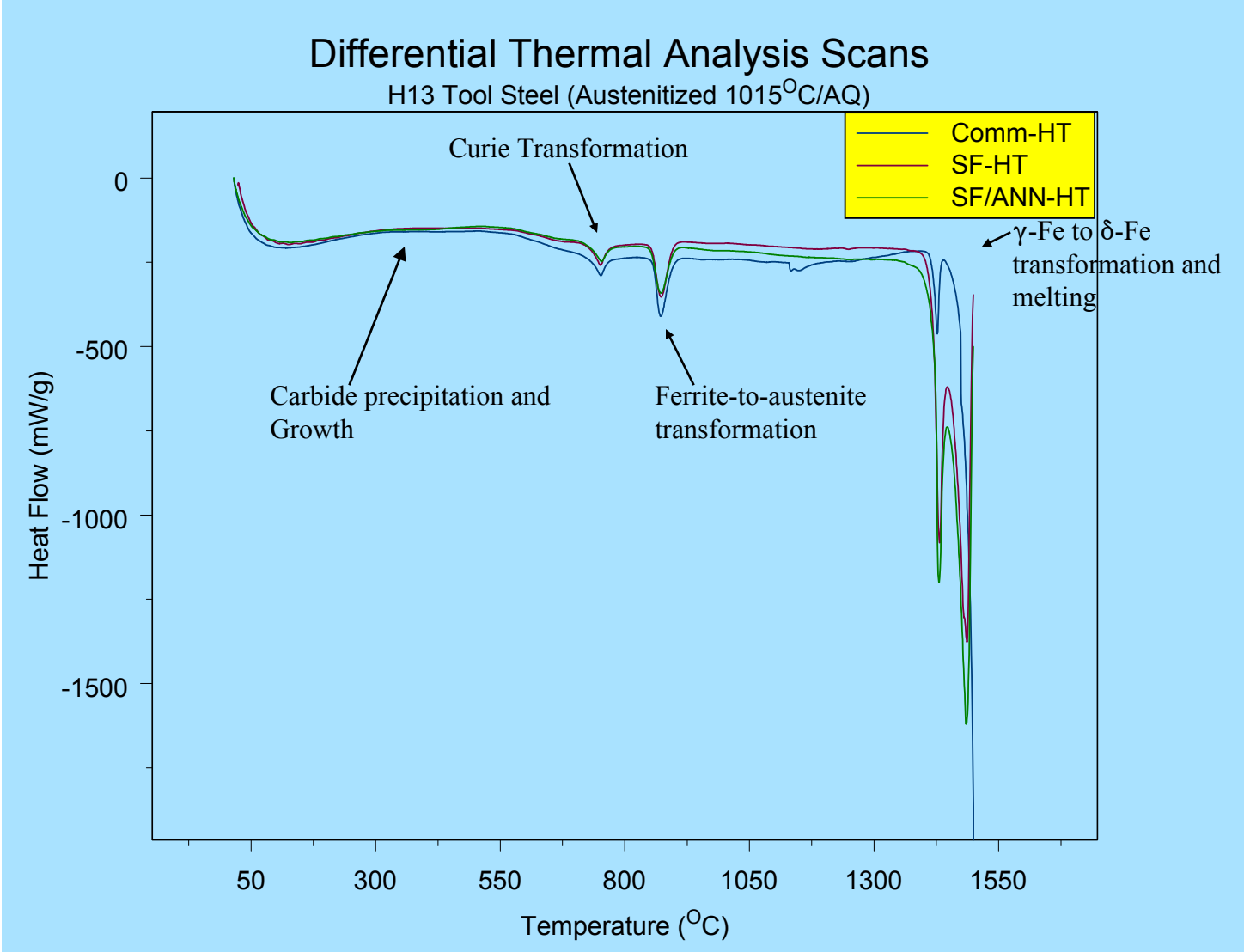

Softening response of H13 tool steel

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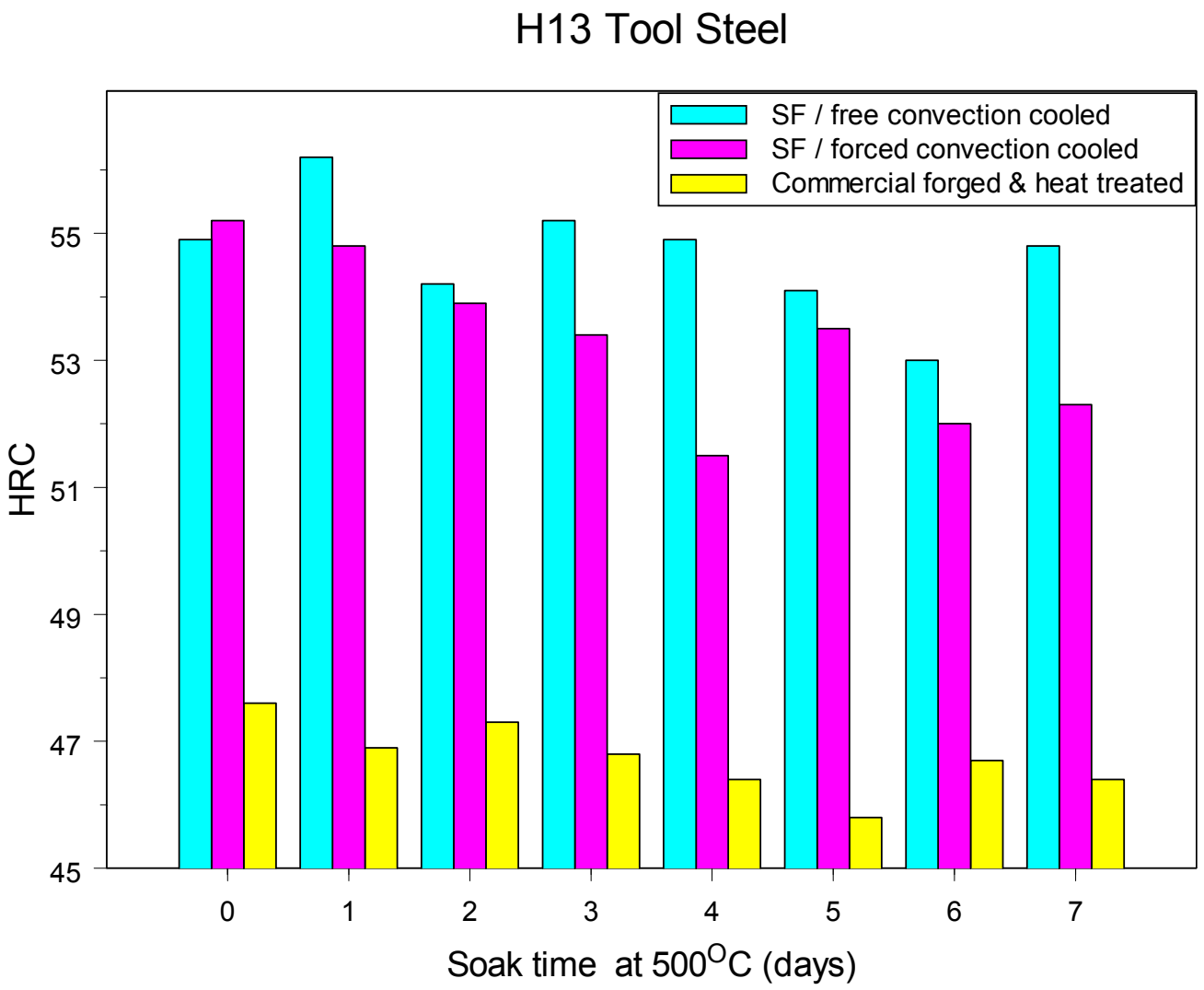

Photomicrographs of M2 tool steel. Spray formed (above), commercial forged (below)

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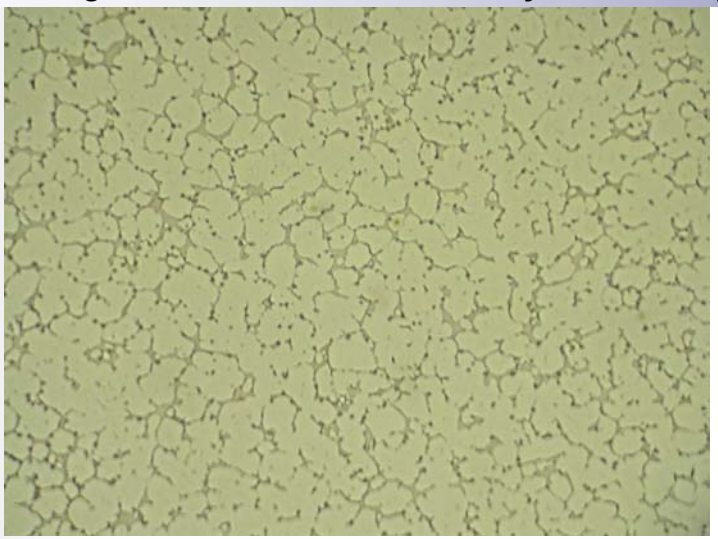

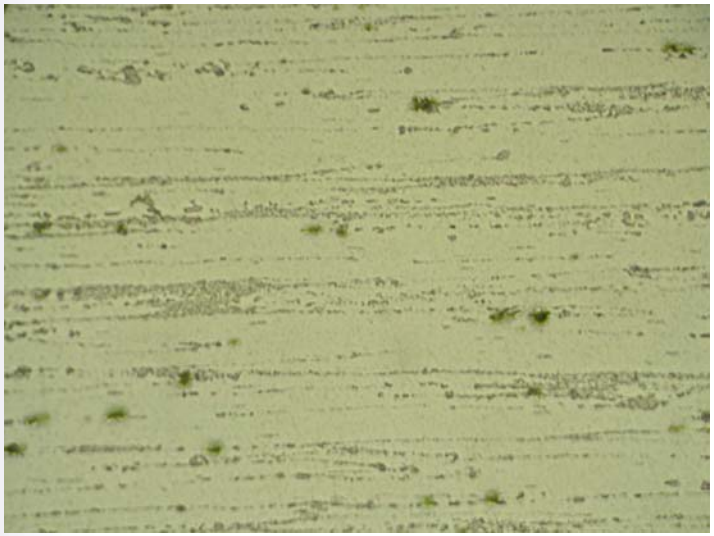

100 X

1000 X

SEM Images of as-deposited A2 steel

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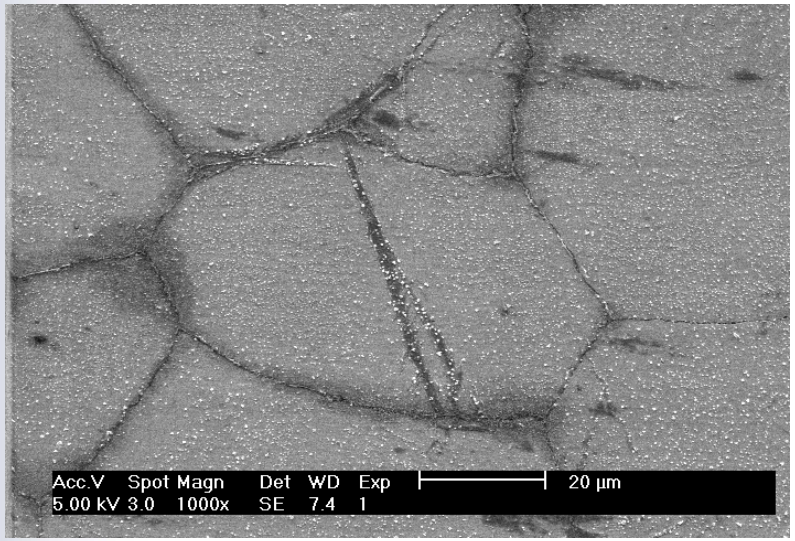

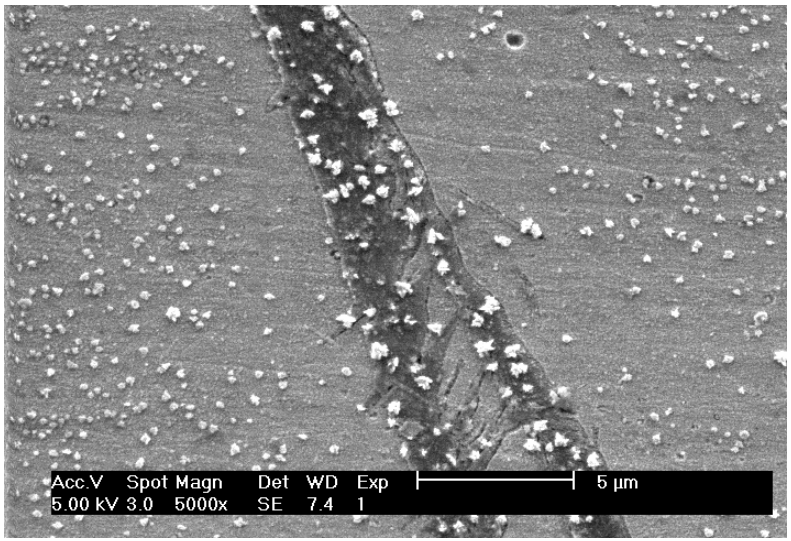

- Plate martensite (black)
- Depletion of carbide around martensite plate

Nital reagent: Ethanol 90 ml and Nitric acid 10 ml; 60 s

Commercial RSP Tooling machine

Commercial beta machine

Industry participants with commercial machine at RSP Tooling, LLC Open House

Patents/Presentations/Publications

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Patents:

- A U.S. patent application entitled "Rapid Solidification Processing System For Producing Molds, Dies, and Related Tooling," is under review by the U. S. patent office.

Presentations:

- An Open House was conducted by RSP Tooling, LLC Feb. 4-7, 2003 in Solon, OH. Approximately 200 people attended. Presentations on RSP Tooling technology were given by INEEL and industry participants in this project.
- K. M. McHugh, "Rapid Solidification Process (RSP) Tooling for Moldmaking," presented at *Moldmaking 2003* Conference and Expo, Cleveland, OH April 29, 2003.

Patents/Presentations/Publications (cont.)

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Publications:

- K. M. McHugh, "Rapid Solidification Process (RSP) Tooling For Moldmaking," proceedings of *Moldmaking 2003* , Cleveland, OH, April 29 – May 1, 2003, P.23 (2003).
- K. M. McHugh and James R. Knirsch, "Producing Production Level Tooling in Prototype Timing– An Update," Moldmaking Technology 5 (10), October 2002, P. 42.
- J. E. Folkstad, J. R. Knirsch, and K. M. McHugh, "Die Casting and Rapid Solidification Process (RSP) Tooling – An Applied Research Project," Proceedings of the 2002 NADCA Congress, Paper T02-051, NADCA, Rosemont, IL, October, 2002.
- J. R. Knirsch, K. M. McHugh, and J. E. Folkestad, "RSP Tooling – A Revolutionary New Process to Manufacture Die Cast Production Tooling in Prototype Timing," Die Casting Engineer 46 (3), May 2002, P. 56.